(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
12 September 2002 (12.09.2002)

PCT

(10) International Publication Number
WO 02/071544 A1

(51) International Patent Classification[7]: H01Q 15/00

(21) International Application Number: PCT/GB02/00734

(22) International Filing Date: 20 February 2002 (20.02.2002)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
0105480.8 6 March 2001 (06.03.2001) GB

(71) Applicant *(for all designated States except US)*: **MARCONI OPTICAL COMPONENTS LIMITED** [GB/GB]; One Burton Street, London W1J 6AQ (GB).

(71) Applicant *(for US only)*: **YOUNG, Ian, Robert** [GB/GB]; High Kingsbury, Kingsbury Street, Marlborough, Wiltshire SN8 1HZ (GB).

(72) Inventor; and
(75) Inventor/Applicant *(for US only)*: **WILTSHIRE, Michael, Charles, Keogh** [GB/GB]; 3 The Brackens, High Wycombe, Bucks. HP11 1EB (GB).

(74) Agent: **WATERS, Jeffrey**; Marconi Intellectual Property, Marrable House, The Vineyards, Great Baddow, Chelmsford, Essex CM2 7QS (GB).

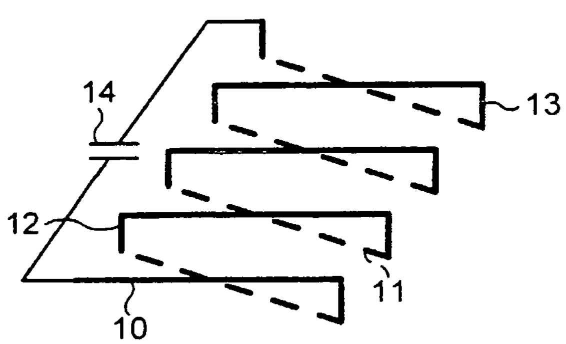
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, OM, PH, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZM, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: STRUCTURES WITH MAGNETIC PROPERTIES



(57) **Abstract:** A surface structure with preselected magnetic permeability in the plane of the surface comprises an array of elements consisting of multi-turn helical loops made for example by tracks (10, 11) on a printed circuit board plated through for example by vias (13) and with the possible addition of a parallel capacitance (14), the pitch of the array being much less than the wavelength of the electromagnetic radiation to which the surface exhibits predetermined values of magnetic permeability, which can range from negative values such as -1 to 0 and to positive values greater than 1. The latter act as a duct for magnetic flux allowing receive coils and magnetic resonance imaging apparatus to be spaced from the surface of a patient and also to allow for screening purposes within magnetic resonance imaging apparatus. A value of magnetic permeability of -1 enables the surface structure to be used as a reflecting surface.

WO 02/071544 A1

STRUCTURES WITH MAGNETIC PROPERTIES

This invention relates to structures with magnetic properties.

A surface structure having magnetic properties for use at GHz (mobile phone) frequencies has been proposed (High-Impedance Electromagnetic Surfaces with a Forbidden Frequency Band, D. Sievenpiper, L. Zhang, R.F. Jiminez Broas, N.G. Alexopolous. E. Yablonovitch, IEEE Transactions on Microwave Theory and Techniques, 1999, **47**, 2059-2074).

The surface is shown in plan in Figure 1 and in cross-section in Figure 2. The surface, which is fabricated as a printed circuit board, consists of a triangular lattice of hexagonal metal plates, connected to a solid metal sheet by vertical conducting vias. One of the plates is designated by the reference numeral 1, the solid metal sheet is designated by the reference numeral 2, and one of the vias is designated by the reference numeral 3. The surface structure has magnetic properties which can be tailored (specifically magnetic permeability) in the plane of the surface over a range of frequencies for which the wavelength is much greater than the period of the surface (so that the structure can be considered to be a homogeneous medium). The permeability varies with frequency and structural design, so the material can be tailored to have a specific permeability at a specific frequency. Since the protrusions 1 are small compared to the operating wavelength, their electromagnetic properties can be described using lumped-circuit elements – capacitors and inductors. There will be capacitance between adjacent plates 1 and circulating currents 5 giving rise to

inductance. The magnetic permeability is exhibited in any direction in the surface of the plane, i.e. radiation with the H-field having an in-plane component will interact with the material. These surface structures are sometimes referred to as magnetic conductors or magnetically conducting planes.

A typical diameter of the metal plates 1 is around 3mm for operation at around 15GHz.

Such surfaces would be of interest for other applications at lower frequencies, for example, 20MHz. However, the dimensions of such a structure would render it too large for many applications.

A bulk structure having magnetic properties for use at GHz frequencies has been proposed (Magnetism From Conductors and Enhanced Non-Linear Phenomena, J.B. Pendry, A.J. Holden, D.J. Robbins and W.J. Stewart, 1999, 47, 2075-2084). In one form, an array of "Swiss roll" resonating structures (Figure 3), one of which is indicated by the reference numeral 7, has magnetic permeability which can be tailored in a direction parallel to the axes of the Swiss rolls i.e. for incoming radiation in the direction 8. The H-field must be parallel to the axes. Again, the range of frequencies over which the magnetic permeability is exhibited applies to wavelengths much greater than the spacing of the rolls. The structure can be considered to consist of lumped circuit resonant elements, inductance being provided by current circulating around the curved wall of the Swiss rolls, and capacitance being provided by the self-capacitance between the inner and outer ends of each roll. In another form, an array of split ring structure 9 arranged in a plane can be stacked to form an array of columns, and has

magnetic permeability in a direction parallel to the axes of the columns. The split ring structures are not shown in detail in Figure 4, but one of the elements is indicated in Figure 5. Each element consists of an inner split ring 9a and an outer split ring 9b. Alternating electrical currents are induced in each ring 9a, 9b, in response to incoming radiation in a direction perpendicular to the plane of the array of rings, whose H-field is parallel to the axes of the rings and so couples to the rings. Despite the break in the slit ring structure, alternating currents can flow by virtue of the self-capacitance between the ends of each ring, and there is also capacitance between the inner ring 9a and the outer ring 9b.

The array of split rings, and an array of spiral elements have, been proposed for use at MHz frequencies e.g. 21MHz (British Patent Application Nos. 0005352.0, 0005349.6), with an array spacing of the order of 6cm, and the multi-layer nature of the construction lends itself to the production of a surface structure. However, because the magnetic permeability takes place in the direction of the axes of the columns of rings, that is, perpendicular to the plane of the array, several layers are necessary to produce a useful value of magnetic permeability. Accordingly, the dimensions of the structure render it too large for many applications.

The invention provides a surface structure with magnetic properties, comprising an array of elements having capacitance and inductance, the structure exhibiting a predetermined magnetic permeability, in the direction in which the surface extends, to incident electromagnetic radiation of a given wavelength greater than the spacing of the

elements, wherein the elements are in the form of conducting multi-turn helical loops arranged with their axes extending generally in the direction of the surface.

A greater inductance is possible for an element of a given loop size since the elements are multi-turn loops, leading to a reduction in the resonant frequency for the structure, which is related to the inverse of the square root of the inductance of the elements.

The invention also provides a surface structure with magnetic properties, comprising an array of elements having capacitance and inductance, the structure exhibiting a predetermined magnetic permeability, in the direction in which the surface extends, to incident electromagnetic radiation of a given wavelength greater than the spacing of the elements, wherein the surface structure is arranged to reflect RF flux.

Such a structure can be used as a reflector for RF flux.

The invention also provides magnetic resonance apparatus, especially magnetic resonance imaging apparatus, which uses a surface structure as defined above as a reflector to direct magnetic resonance signals to a receive coil.

Advantageously, the predetermined magnetic permeability is exhibited to incident electromagnetic radiation of a wavelength at least two times greater than the spacing of the elements, preferably at least five times greater than the spacing of the elements. There may be advantages if the wavelength is ten times or one hundred times the element spacing.

The invention will now be described in detail, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a plan view of a known surface structure with magnetic properties;

Figure 2 is a front view of the surface structure of Figure 1 showing only the first line of plates;

Figure 3 is a schematic perspective view of a known bulk structure with magnetic properties;

Figure 4 is a plan view of one layer of a known multi-layer bulk structure with magnetic properties;

Figure 5 is a plan view of one element of the array shown in Figure 4;

Figure 6 is a perspective schematic view of one element of a surface structure with magnetic properties in accordance with the invention;

Figure 7 is a plan view of the element shown in Figure 6;

Figure 8 is a plan view of an alternative form of one element of a surface structure with magnetic properties in accordance with the invention;

Figure 9 indicates a symbol which represents the plan view of the forms of element shown in Figure 7 and Figure 8;

Figure 10 is a schematic view, using the symbol shown in Figure 9, of a uniaxial surface structure in accordance with the invention;

Figure 11 is a schematic view, using the symbol shown in Figure 9, of a biaxial surface structure in accordance with the invention;

Figure 12 is a schematic front view of another form of element of a surface structure with magnetic properties in accordance with the invention;

Figure 13 is a plan view of surface structures with magnetic properties in accordance with the invention, positioned for imaging above an abdomen;

Figure 14 is a front view of the surface structures shown in Figure 13;

Figure 15 is a schematic axial sectional view through a part of a magnetic resonance imaging apparatus employing a known RF screen;

Figure 16 is an enlarged cross-sectional view, compared to Figure 15, of a part of a magnetic resonance imaging apparatus employing an RF screen in the form of a surface structure with magnetic properties in accordance with the invention; and

Figure 17 is a schematic representation of a reflecting surface in the form of a surface structure with magnetic properties according to the present invention forming part of magnetic resonance imaging apparatus.

Referring to Figure 6 and 7 of the drawings, one element having inductance and capacitance is illustrated, and a surface structure is made up of an array of such elements, for example a rectangular array of elements arranged in a plane.

Each element consists of a multi-turn helical loop of rectangular form. The loop is made up of tracks 10 (shown in solid line) on the upper surface of a double-sided printed circuit board (not shown), tracks 11 (shown dotted) on the lower side of the printed circuit board, and vertical conducting vias 12, 13 completing the loops. The vias 12, 13 may be plated through or pinned connections. The element as described is primarily an inductor, but does have some self-capacitance between the first and last turns of the loop. However, an additional capacitance 14 is connected in parallel with the loop. This capacitance may be surface mounted, for example.

The element thus described may be replicated over the surfaces of a double-sided printed circuit board, with the multi-turn loops being arranged with their axes parallel to each other, to form a surface structure with magnetic properties according to the present invention.

The resonant frequency of each element is more of less proportional to the square root of the inverse of the product of the inductance and the capacitance (it being partly

dependent on residual resistance), and the resonant frequency of the surface structure is influenced mainly by the resonant frequency of each element, although also partly by the arrangement of the elements in the form of the array. The capacitance 14 increases the product of the inductance and capacitance of the element, and therefore decreases its inverse and the square root of its inverse, thereby lowering the resonant frequency for the surface structure. This resonant frequency, or more properly, band of frequencies, define the frequencies for which the surface structure has magnetic properties, that is, predetermined values of magnetic permeability. This varying magnetic permeability is exhibited for electromagnetic radiation that has a component of its H-field in the plane of the printed circuit board, and parallel to the axes of the multi-turn loops. Over the range of frequencies for which the surface structure has magnetic properties, the H-vector predominates, and can be considered to be aligned with the direction of propagation of the electromagnetic radiation. The surface structure is thus uniaxial.

Typical dimensions for the form of elements shown in Figures 6 and 7, providing operation at a frequency in the region of 20MHz are: five turns of the loop with a surface track width of around 0.5mm and length around 25mm, on each side of a board which is 3.2mm thick bearing 2oz copper (per square foot, corresponding to approximately 70μm thickness), corresponding to the tracks being approximately 70μm in thickness. The additional capacitance required is around 1.5nF.

In a second embodiment of element of the array, in Figure 8 a double-wound form of element is shown. Each of the windings is identical to those shown in Figure 6 and 7, but two such windings are placed closely adjacent to each other. This has the effect of

minimising the amount of external capacitance. Interleaving the windings increases the stray capacitance between the two, and the inductance is a function of the total number of turns (in both windings). The double wound structure provides more inductance, as there are more turns, more self-capacitance, from the side-by-side windings, and so a lower resonant frequency. Alternatively, for the same frequency, fewer turn are needed, resulting in smaller structures which can be more tightly packed to give bigger resonances.

Thus, one multi-turn loop consists of tracks 15 on the top of the board and 18 on the bottom of the board, in parallel with capacitor 20, and the other multi-turn loop consists of tracks 16 on top of the board and tracks 17 on the bottom of the board connected to capacitor 19, the loops being connected by vertical connections, each loop being connected by vertical connections as for the element shown in Figure 6.

Using the symbol of Figure 9, which represents the elements of Figure 6 and 7 on the one hand and Figure 8 on the other hand, in the orientations shown in Figures 7 and 8, two possible surface structures are shown in Figures 10 and 11.

In Figure 10, a regular array of either form of element is formed on the double sided printed circuit board, with the loops running from side to side of the boards and the axes of the loop running from top to bottom of the boards. The board 21 exhibits magnetic permeability to incoming radiation in the plane of the board and in the direction 22, the H-vector being considered to be running parallel to the axes of the loops. With the board 23 (also flat) in Figure 11, alternate elements of the array are arranged at right

angles to each other, so that the axes of the loops are alternately arranged from top to bottom of the board, in the case of the top left element, from side to side of the board in the case of the second element from the left in the top row, etc. Such a surface structure exhibits magnetic permeability in two directions at right angles in the plane of the board, and is thus biaxial. It follows that magnetic permeability is exhibited in any direction in the plane of the board.

The spacing of the elements of the array may be less than half the wavelength in the predetermined band at which the predetermined magnetic permeability is exhibited, and preferably less than a fifth or less than a tenth of that wavelength. The magnitude of the magnetic permeability, and the band of frequencies over which the predetermined magnetic permeability is exhibited, is largely dependent on the inductance and capacitance of each resonant element, but these quantities will also change a little when the spacing of given elements is changed.

In other words, changing the pitch acts on two aspects of the performance. More turns per unit length increases the self-inductance and hence reduces the resonant frequency. More elements per square centimetre means a higher packing density, and so a larger excursion in the permeability curve i.e. large values of permeability become available.

Referring to Figure 12, an alternative form of element is shown. These are also arranged in any array (not shown) like those in Figures 10 and 11. This consists of a multi-layer board, the layers being 25, 26 and 27. The layer 25 has tracks 28 running from side to side of the board on its upper surface, and tracks 31 running from front to

back of the board, on its lower surface, into the plane of the paper as seen in Figure 12. A spacer 26 spaces the board 25 from a board 27 which has tracks 29 running from side to side of the board on the top and tracks 32 running from front to back (into the plane of the paper) on its lower surface. The tracks 28 and 29 are connected by vias such as 30 and the tracks 31 and 32 are connected at the front and back of the board by vias (not shown). It will be seen that each element consists of a loop of the form shown in Figure 6 interleaved with another loop of the form shown in Figure 6 which remains in the same plane but has been turned around through 90°. Thus, each element exhibits magnetic permeability in any direction in the plane of the board. Additional capacitance can be provided by surface mount capacitors on the top of the board for the turns defined by the tracks 28, 29 and on the lower surface of the board by the turns defined by the tracks 31 and 32. This corresponds to the arrangement of Figure 11 but <u>each</u> element is biaxial, resulting in a greater packing density. This is desirable to improve magnetic permeability performance in the plane. The inductance and capacitance which control the resonance arise from the winding regarded as a whole, while any in-plane flux couples with the winding. A stronger resonance will be provided, and hence a wider range of frequencies.

The magnetic permeability <u>normal</u> to the surface structures described is unity i.e. that of free space.

Of course, variations may be made without departing from the scope of the invention. Thus, there is no need for the loops to be of the rectangular form shown. Other rectangular dimensions are possible and, indeed, on a suitable mount, the loops need not

be rectangular at all, they could be circular arranged on cylindrical mounts. There is no need for the tracks to be plated onto the board, winding of wires would be possible for the elements. While a large plane surface structure could be made from an array of the elements as described, there may be instances where a non-planar surface is desirable. Thus, a dished shape of surface could be provided by arranging for the surface to be made up of relatively small elements such are as shown in Figures 10 and 11 of flat shape. Another possibility would be for a board to be fabricated to a desired curved shape, for example in the case of a reflector, designed to focus radiation emanating from a particular region to another region, and the elements could then be printed onto this curved surface.

While the elements have been shown in conjunction with additional capacitance, there may be circumstances where this could be dispensed with, relying on the self-capacitance of the multi-turn loops.

While the surface structures described exhibit predetermined values of magnetic permeability primarily in the HF band (wavelength 10m–100m), the surface structure would also exhibit magnetic permeability in the MF band (wavelength 100m-1000m), and in the VHF and UHF bands (wavelength 1m-10m and 0.1m-1m), and higher frequencies.

The pitch spacing is less than the wavelength at which magnetic permeability is exhibited, and is preferably less than at least one tenth of that wavelength.

The bandwidth over which the magnetic permeability varies depends on the balance of inductance and capacitance, and is defined by the width of the resonance (determined by the dissipation or damping in the structures, and mainly due to the resistance of the loops), and by the strength of the resonance, determined by the packing density of the loops.

The surface structures described could have magnetic permeabilities which are positive and greater than unity, preferably which range from 4 to 5 and upwards, to act as a duct, in the manner described in our co-pending British Patent Application No. 0005349.6, zero value or negative value as described in our British Patent Application No. 0005352.0 in order to act as a screen, or the value of –1 as described in British Patent Application No. 0015067.2.

One example of a flux guide is shown in Figures 13 and 14, in which a portion of a human abdomen 34 is illustrated, in the imaging region of magnetic resonance imaging apparatus.

In order to image a sensitive region 41, instead of a surface coil being placed on the nearest region of the surface of the patient, paddle-shaped flux guides 35, 36, 37 are placed on the surface of the patient in order to duct flux from the regions of the ends of the guides through the guides and, in particular, through the narrow neck region at which a receive coil 38, 39, 40 is wound, where the magnetic resonance signal may be picked up.

There are two advantages of such an arrangement. The receive coils 38 to 40 are spaced from the surface of the patient and can therefore be refrigerated. Secondly, the region of the patient immediately above the sensitive region 41 is left free in order for possible invasive surgery to take place which can be monitored in real time by viewing the magnetic resonance image. Another advantage is that there is no mutual inductance between the guides 35, 36, 37, allowing the receive coils to be used in conjunction with techniques which use an array of coils to enable image space to be undersampled by relying on coil relative position and sensitivity profiles to generate missing data (Simultaneous Acquisition of Spatial Harmonics (SMASH): Fast Imaging with Radio Frequency Coil Arrays, Daniel K Sodickson, Warren J Manning, MRM38: 591-603 (1997)).

Typical values of the magnetic permeability are in excess of 4.

As an alternative to the ducting arrangements of Figures 13 and 14, the surface structure of the invention may be used for screening.

Thus, referring to Figure 15, which represents a magnetic resonance imaging apparatus, magnetic resonance is excited in a whole body typically using a so-called birdcage coil, consisting of a number of conductors 42 which extend along the surface of a notional cylinder and are joined by rings at each end of the notional cylinder. This is used to generate RF excitation pulses to excite resonance in a sensitive region being imaged. Clearly, such a birdcage coil will also emit RF radiation outwardly as well as inwardly to the desired region, and such radiation would couple with the metal of the imaging

apparatus surrounding the coil, which would distort the RF magnetic fields and affect machine performance. For this reason, it is standard practice to employ a mesh screen 43 to dissipate the power from the RF pulses through eddy currents in the screen. In practice, such a conventional screen cannot be too close to the conductors since then most of the RF power is dissipated in the screen.

Referring to Figure 16 which is on a greatly enlarged scale compared to Figure 15, a single conductor 45 of a birdcage coil is shown and a surface structure of the present invention used as a screen 46, circular like that of Figure 15, is arranged more closely adjacent thereto than is the screen 43 of the prior art arrangement of Figure 15. The surface structure 46 acts as a flux guide, so that, as far as the flux line 47 is concerned, there is a lower reluctance path along the guide than along the path (shown dotted) it would have taken if the screen were not present.

Typical magnetic permeabilities for this case would be substantially greater than 1, preferably greater than 2, advantageously greater than 4.

One advantage of the screening surface structure 46 is that the structure can be placed nearer to a conductor 45 of the birdcage coil than hitherto. A second advantage is that the flux is ducted around the screening surface structure, rather than being dissipated, so that less power is needed in the means to generate the RF excitation pulse.

A surface structure which acts as a mirror is shown in Figure 17 where surgery is to be carried out on a region such as 50 on the cranial region of a patient 51. A surface

structure according to the invention 48 used as a mirror may be used to reflect magnetic resonance signals received from the sensitive region 50 onto a receive coil 49 spaced away from the surface of the patient. The advantage of this is that the receive coil 49 is not in contact with the surface of the patient, which is a very great advantage if the imaging operation is to be performed at the same time as surgery, where maintenance of sterile conditions is very important.

The value of magnetic permeability to which the surface structure would be tuned in the case of Figure 17 would be -1.

The patient shown in Figure 17 is positioned in magnetic resonance imaging apparatus, and magnetic resonant active nuclei in a sensitive region in which a large, constant, magnetic field is set up, such as the region 50, are excited by an RF excitation pulse, enabling magnetic resonance signals representative of the excited region to be generated. These are detected by the receive coil 49.

The surface structure 48 behaves like a mirror provided the RF flux is reflected at grazing or near grazing incidence (in the region of less than 15° away from the grazing incidence). Normally incident radiation will go straight through the surface structure. The surface structure can thus be likened to the optical reflecting properties of a block of glass.

At near grazing incidence, the magnetic permeability could be a substantial, positive, value, and the surface structure would still work as a reflector, but in this case, the

radiation will tend to be ducted through the material, rather than being reflected by it (as in the case described of a value of –1 for the magnetic permeability).

The surface structure can be used for reflecting received magnetic resonance signals to a receive coil, or for reflecting the excitation pulses to a sensitive region. More generally, the reflecting surface could be used whenever it is desired to direct RF flux, for example, where it is desired to heat tissue to destroy it for treatment purposes.

CLAIMS

1. A surface structure with magnetic properties, comprising an array of elements having capacitance and inductance, the structure exhibiting a predetermined magnetic permeability, in the direction in which the surface extends, to incident electromagnetic radiation of a given wavelength greater than the spacing of the elements, wherein the elements are in the form of conducting multi-turn helical loops arranged with their axes extending generally in the direction of the surface.

2. A surface structure with magnetic properties, comprising an array of elements having capacitance and inductance, the structure exhibiting a predetermined magnetic permeability, in the direction in which the surface extends, to incident electromagnetic radiation of a given wavelength greater than the spacing of the elements, wherein the surface structure is arranged to reflect RF flux.

3. A surface structure as claimed in Claim 1 or Claim 2, wherein multi-turn helical loops of each element include lengths extending along opposed surfaces of a board.

4. A surface structure as claimed in Claim 3, in which the lengths are joined by connections from side to side of the board.

5. A surface structure as claimed in Claim 4, in which the connections are plated through.

6. A surface structure as claimed in any one of Claims 3 to 5, including a respective capacitor mounted on the board in parallel with each element.

7. A surface structure as claimed in Claim 6, in which the capacitors are surface mounted.

8. A surface structure as claimed in any one of Claims 1 to 7, in which each element includes a second multi-turn helical loop.

9. A surface structure as claimed in any one of Claims 1 to 8, wherein at least some of the elements of the array are orientated with their axes inclined to those of the other elements.

10. A surface structure as claimed in any one of Claims 1 to 9, wherein at least some of the elements are orientated with their axes included at least 90° to those of the other elements.

11. A surface structure as claimed in Claim 9 or Claim 10, in which alternate elements in the array in the row and the column direction are orientated with their axes at 90° to each other.

12. A surface structure as claimed in any one of Claims 3 to 8, including a multi-layer board with a second array of elements in the form of conducting multi-turn helical loops arranged with their axes extending generally in the direction of the surface, wherein the elements of one array are arranged with their axes at right angles to those of

the respective elements of the second array, and respective elements of each array being superimposed.

13. A surface structure as claimed in any one of Claims 1 to 12, in which the surface is plane.

14. A surface structure as claimed in any one of Claims 1 to 12, in which the surface is curved.

15. A surface structure as claimed in Claim 2, in combination with a receive coil of magnetic resonance apparatus.

16. A surface structure substantially as herein described with reference to the accompanying drawings.

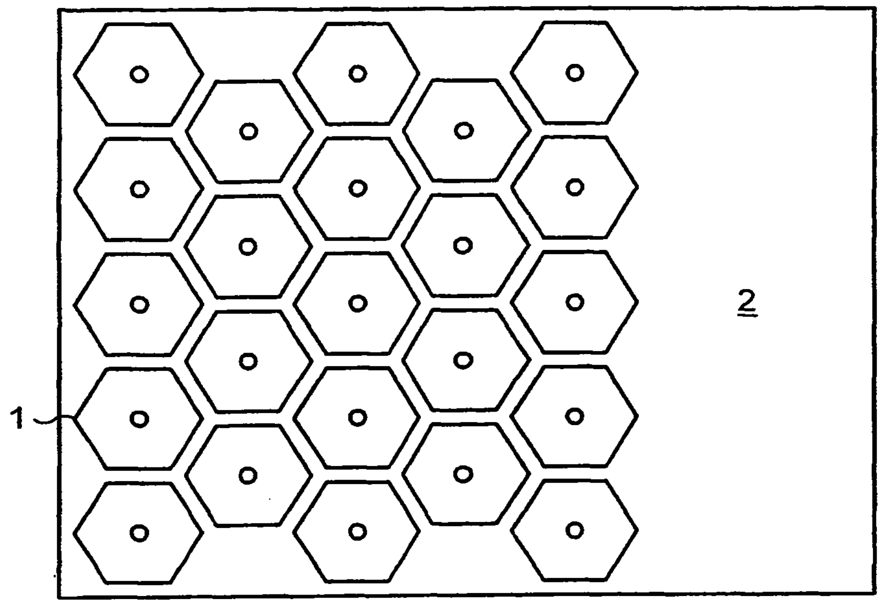


FIG. 1
PRIOR ART

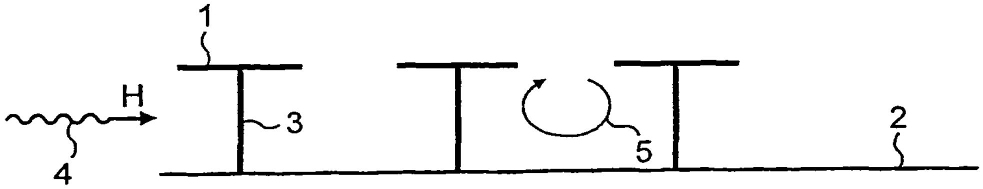


FIG. 2

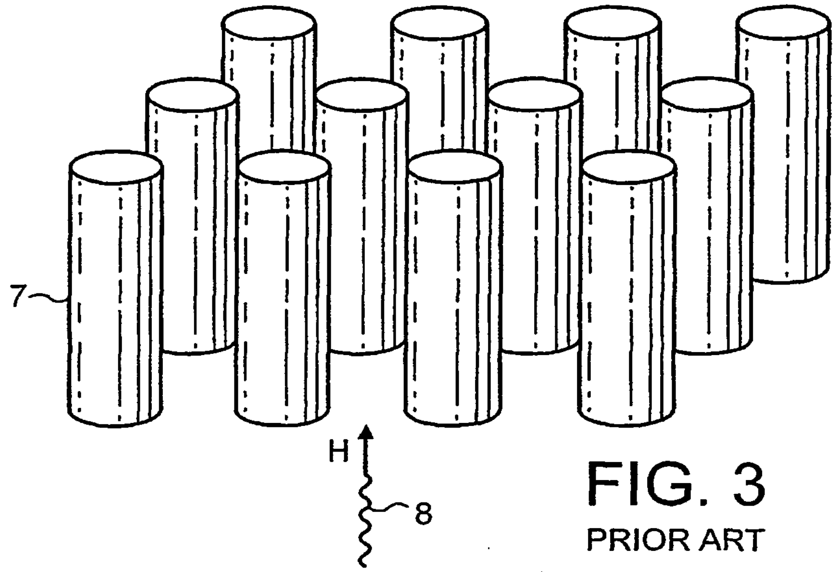


FIG. 3
PRIOR ART

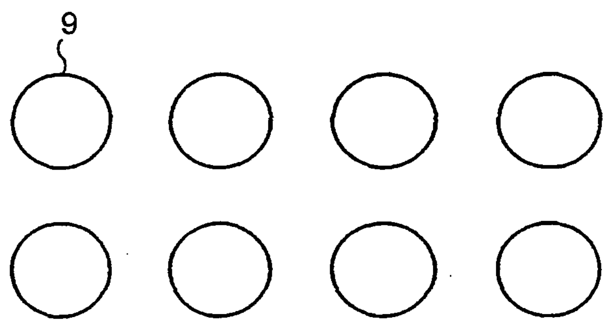


FIG. 4
PRIOR ART

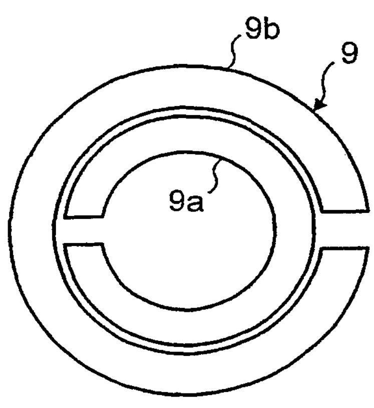


FIG. 5

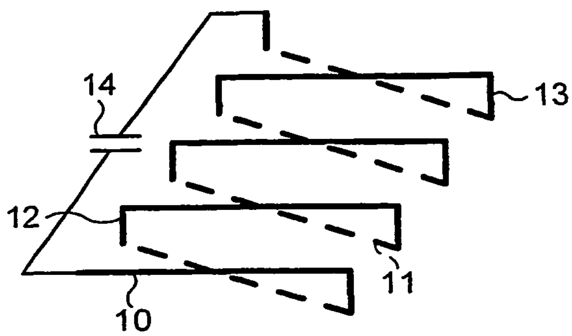


FIG. 6

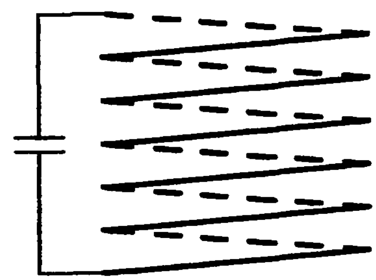


FIG. 7

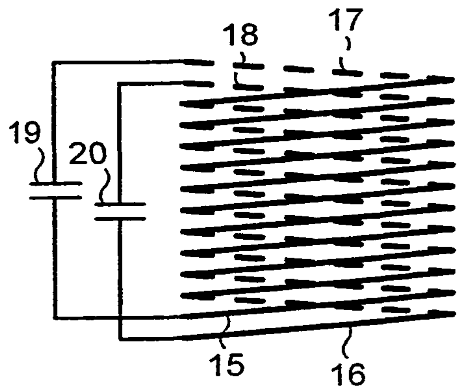


FIG. 8

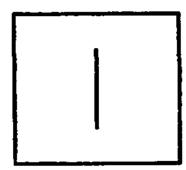


FIG. 9

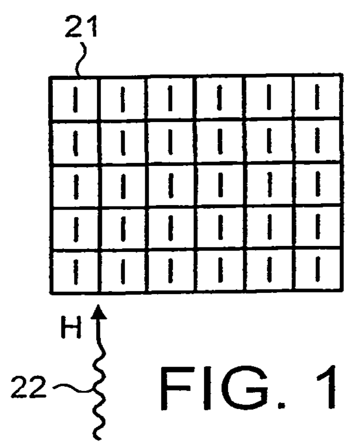


FIG. 10

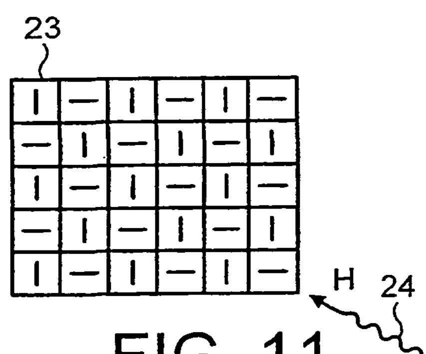


FIG. 11

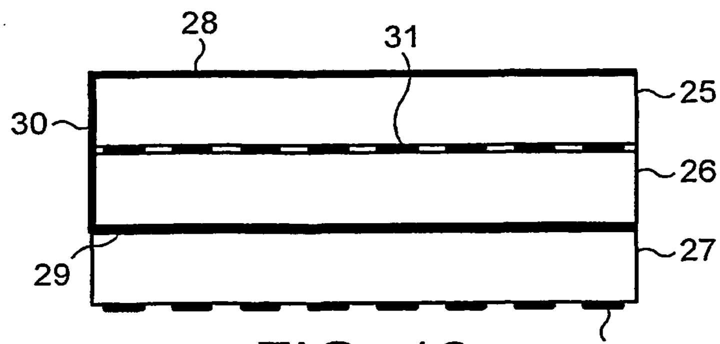


FIG. 12

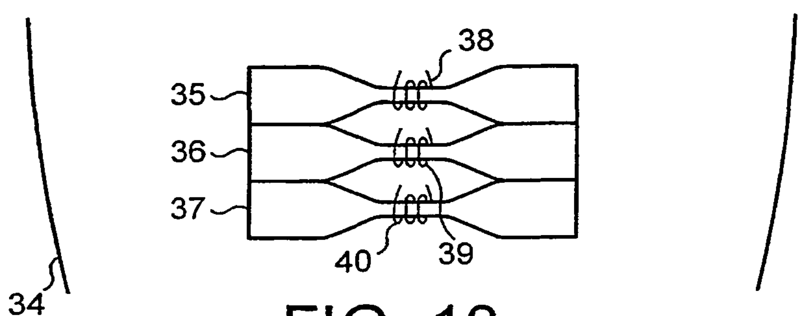


FIG. 13

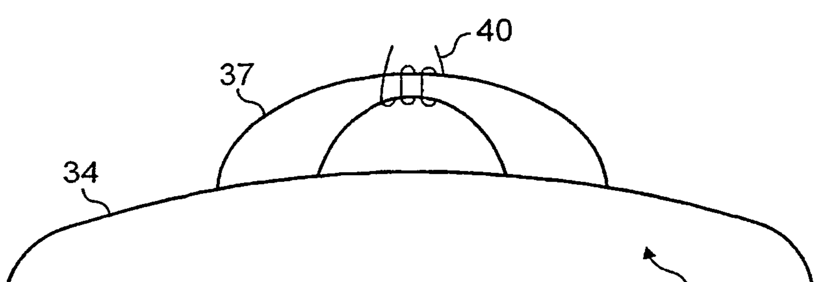


FIG. 14

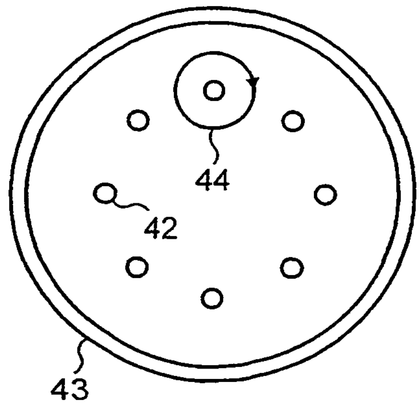


FIG. 15
PRIOR ART

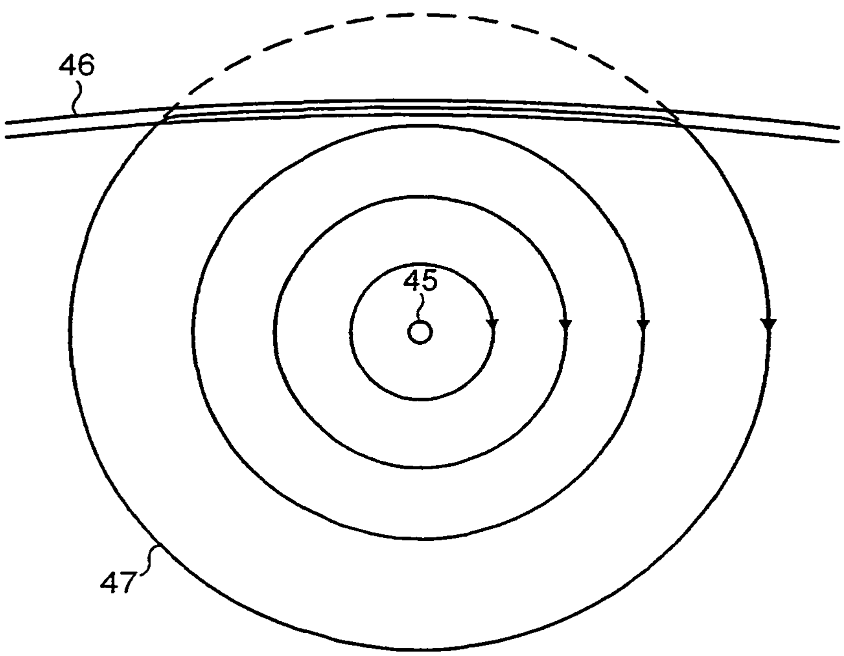


FIG. 16

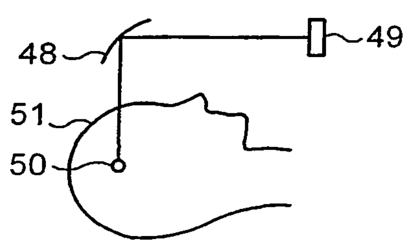


FIG. 17

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB[illegible]2/00734

A. CLASSIFICATION OF SUBJECT MATTER IPC 7 H01Q15/00 According to International Patent Classification (IPC) or to both national classification and IPC		
B. FIELDS SEARCHED Minimum documentation searched (classification system followed by classification symbols) IPC 7 H01Q		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched		
Electronic data base consulted during the international search (name of data base and, where practical, search terms used) EPO-Internal, PAJ, WPI Data		

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PENDRY J B ET AL: "MAGNETISM FROM CONDUCTORS AND ENHANCED NONLINEAR PHENOMENA" IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES, IEEE INC. NEW YORK, US, vol. 47, no. 11, November 1999 (1999-11), pages 2075-2084, XP000865104 ISSN: 0018-9480 abstract ---	2,13,16
A	WO 00 41270 A (MARCONI CASWELL LTD ;PENDRY JOHN BRIAN (GB); ROBBINS DAVID JAMES () 13 July 2000 (2000-07-13) cited in the application abstract --- -/--	1-16

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 June 2002	25/06/2002
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Wattiaux, V

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		
Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
P,X	WO 01 24313 A (ROCKWELL SCIENCE CT LLC) 5 April 2001 (2001-04-05) the whole document ---	1-4,6, 8-10
P,X	GB 2 363 845 A (MARCONI CASWELL LTD) 9 January 2002 (2002-01-09) the whole document -----	2,13,15, 16

INTERNATIONAL SEARCH REPORT

International Application No
PCT/G[illegible]2/00734

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
WO 0041270	A	13-07-2000	AU	1988500 A	24-07-2000
			CA	2322514 A1	13-07-2000
			WO	0041270 A1	13-07-2000
			GB	2346485 A ,B	09-08-2000
WO 0124313	A	05-04-2001	WO	0124313 A1	05-04-2001
GB 2363845	A	09-01-2002	AU	7430001 A	14-01-2002
			WO	0203500 A1	10-01-2002

Form PCT/ISA/210 (patent family annex) (July 1992)